

Atmospheric conditions analysis of the heavy rain phenomenon in Biak (case study 4-5 December 2014)

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Abstract Heavy rain in Biak on 4-5 December 2014 caused a flood. The accumulation of rainfall until 5 December was 102 mm, it exceeded BMKG's threshold about the intensity of extreme condition. This research aimed to find out the atmospheric conditions related to super heavy rain phenomenon. The atmospheric dynamical analysis used ERA-Interim Reanalysis data 0.125x0.125 degrees resolution. Divergence, relative vorticity, and streamline are the parameters investigated. Their dynamic fluctuations in significant pressure levels proved there were strong convergence and negative vorticity. Streamline analysis showed that there was a convergence wind pattern. While, the physical analysis used NOAA/NESDIS SST data to find sea surface temperature anomaly, RMM index data to find MJO phase and ONI index data to find ENSO phase. At the time, SST around Biak was in warmer condition, and there was a weak El Nino influenced by moderate MJO phase 5. Upper air sounding analysis is used to study the predictability of extreme weather. The indices indicated moderately convective activity and very unstable atmospheric layer before the event, while marginally convective activity and unstable boundary layer with possible inversion aloft during the event. All the conditions supported to produce convective cloud (Cumulonimbus) so that cloud had a long lifetime and produced thunderstorm and heavy rainfall. Biak meteorological station observation and MTSAT imagery used to verify the atmospheric conditions.

1. Introduction

On 4-5 December 2014, super heavy rain caused flooding in the city of Biak and became one of the phenomena disrupted the flight activities at the Frans Kaisiepo Biak airport for several hours, and causing waterlogging even flooding in some areas in Biak. The accumulated rainfall measured in Biak Meteorological Station was 102 mm per day. It is included one extreme weather phenomenon according to the Indonesian Agency for Meteorological, Climatological, and Geophysics (BMKG) is super heavy rain with an intensity of more than 20 mm per hour or more than 100 mm/day [4]. From the rainfall data, the super heavy rain case in the city of Biak with intensity exceeded extreme values threshold of BMKG.

Biak is one of the districts in the province of Papua, Indonesia. The seas and oceans around Biak made variability of weather and climate in the region influenced by the interaction of ocean and

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atmosphere. The global phenomena such as El Nino, La Nina, and MJO (Madden-Julian Oscillation) also gave impact to the weather and climate in Biak, as well as regional scale like monsoon circulation, the ITCZ (Inter-Tropical Convergence Zone), and the local influences.

Extreme weather is a state or physical phenomena in the atmosphere of a place, at a particular time-scale and short-term which is BMKG categorized if surface air temperature $\geq 35^{\circ}\text{C}$, wind speed ≥ 25 knots, and the rainfall in a day ≥ 50 mm [14]. Extreme weather conditions are output from significant conditions happened to the weather parameters. This paper examined the atmospheric conditions during the super heavy rain phenomenon in Biak on the dates.

2. Methodology

To find out the atmospheric conditions during heavy rain in Biak on 4-5 December 2014, this paper investigated the dynamics and physical aspects of weather parameters. The atmospheric dynamical analysis used ERA-Interim Reanalysis data $0.125^{\circ}\times 0.125^{\circ}$ degrees spatial resolution. Divergence, relative vorticity, and streamline were the parameters investigated. Pressure levels used were significant layers of 1000, 925, 850, 700, 500, 400, 300, 200, 150, and 100 hpa. The 850 hpa level, there was the dynamics of the atmosphere that representative for tropospheric weather variability under highly influenced by the state of the Earth's surface. The 500 hpa level of variability that described the dynamics of the middle troposphere. And 300 hpa level represented the dynamics of the atmosphere at the upper-level troposphere.

While, the physical analysis investigated SST anomaly, MJO phase, and ENSO phase. The SST anomaly data were NOAA/NESDIS SST100 $1^{\circ}\times 1^{\circ}$ degrees spatial resolution to found the sea surface temperature anomalies. The data were composite gridded-image derived from 8-km resolution global SST observations and generated daily on a global scale.

OLR anomalies and RMM index data were used to found MJO phase. Outgoing longwave radiation (OLR) is used as a way to identify tall, thick, convective rain clouds. The NOAA OLR anomalies maps showed the difference from expected cloudiness based on the position of the MJO. The violet and blue shading indicated higher than normal, active or enhanced tropical weather, while orange shading indicated lower than normal cloud or suppressed conditions. The MJO diagram illustrated the progression of the MJO through different phases, which coincided with locations along the equator around the globe. RMM1 and RMM2 are mathematical methods that combine cloud amount and winds at upper and lower levels of the atmosphere to provide a measure of the strength and location of the MJO [3]. When the index is within the center circle, the MJO is considered weak, meaning it is difficult to discern using the RMM methods. Outside of this circle the index is stronger and will usually move in an anti-clockwise direction as the MJO moves from west to east. There were eight different MJO phases in the diagram.

While ONI index data used to found ENSO phase. Oceanic Nino Index (ONI) was three months running mean of ERSST.v4 SST anomalies in the Niño 3.4 region ($5^{\circ}\text{N} - 5^{\circ}\text{S}$ and $120^{\circ} - 170^{\circ}\text{W}$), based on centered 30-year base periods updated every five years. In this case, ONI used 1981-2010 base periods. Warm (El Nino) periods based on a threshold of $+ 0.5^{\circ}\text{C}$ and cold (La Nina) based on a threshold of $- 0.5^{\circ}\text{C}$.

Upper air sounding analysis was used to study the predictability of extreme weather. The upper air data used rawinsonde of Biak meteorological station observation provided by the University of Wyoming. The parameters investigated were CAPE, K Index, Lifted Index, Sweat Index, and Showalter Index by analyzing based on the threshold values. MTSAT imagery used to verify the atmospheric conditions.

3. Results and Discussion

3.1. The Atmospheric Dynamical Analysis

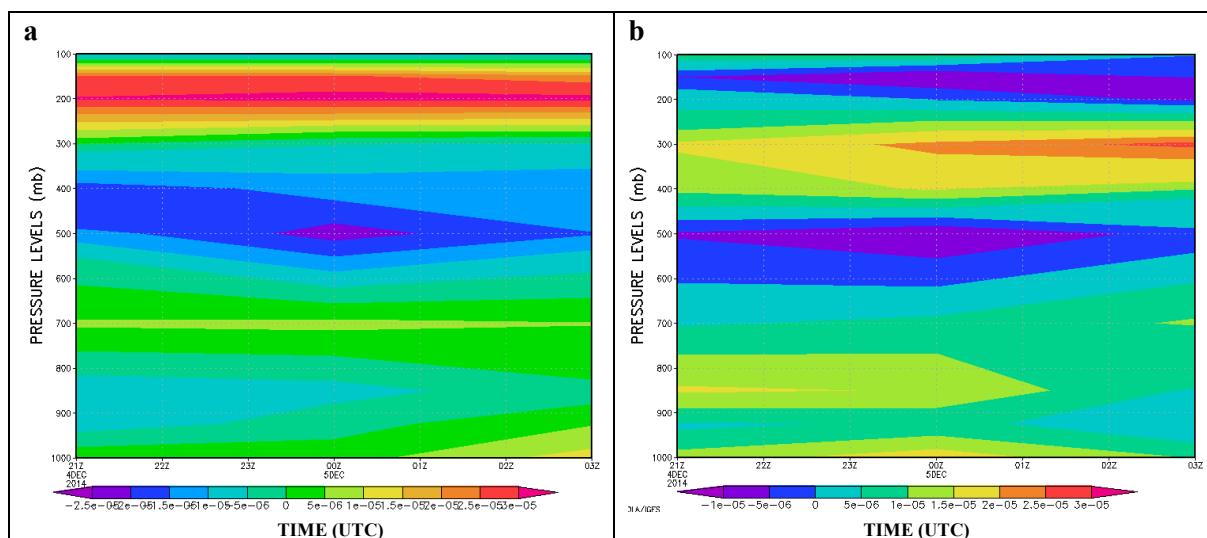


Figure 1. (a) Divergence in Biak; (b) relative vorticity in Biak on 4-5 December 2014

Figure 1 (a) showed that in 850mb level, negative divergence occurred in the range $-0.5 \text{ e}^{-5} \text{ s}^{-1}$ to $-1 \text{ e}^{-5} \text{ s}^{-1}$. The divergence in each layer varied to heights. In the higher level of 200 hpa, there was strong positive divergence. Divergence is a vector field that showed the flow in the atmosphere. A positive divergence in the upper-level and a negative in the lower level of troposphere indicated rising air movement. The more positive value of divergence, the air mass diverged and sank. The more negative value, the stronger the convergence indicated the growth of clouds. In the area of convergence activities occurred convection that formed many convective clouds.

Relative vorticity indicated the direction of rotation of air mass in the atmosphere on the micro scale. Due to Biak location in the southern hemisphere, the (+) values indicated the anticyclonic movement, while the (-) values indicated cyclonic rotation. The greater the magnitude of vortices, the stronger anticyclonic movement of air mass so that the chances of the formation of clouds getting smaller because of the air mass spread. Figure 1 (right) showed the relative vorticity at 500 hpa level reached $-9 \text{ e}^{-6} \text{ s}^{-1}$, indicated a cyclonic movement (clockwise rotation). In the southern hemisphere, the more negative vorticity values, the greater the convection currents that occurred, leading the formation of clouds.

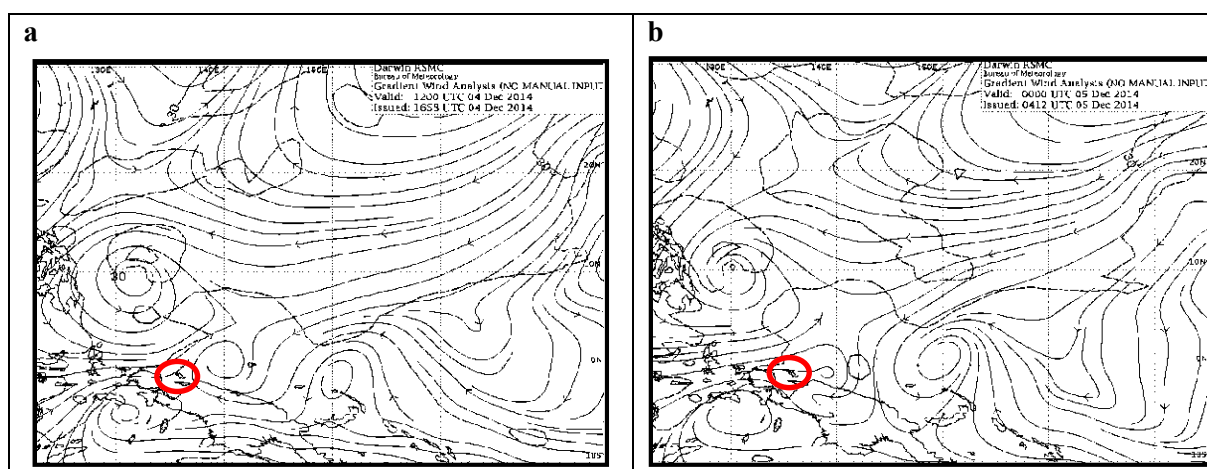


Figure 2. Streamline map at 3000 feet on 4 December 2014 (a) at 12.00 UTC and 5 December 2014 (b) at 00.00 UTC

An extreme weather phenomenon can be analyzed by using streamline map to describe the atmospheric condition. Streamline map included as synoptic scale analysis where the wind data from many observation stations were spatially analyzed. The synoptic analysis is a way of studying the weather system at a specific time on a large scale [15]. Based on the streamline map on 4 December 2014 at 12.00 UTC and 5 December 2014 at 00.00 UTC from BOM (Bureau of Meteorology) in Figure 2, wind patterns at an altitude of 3000 feet showed that there was a low-pressure area in the north of Papua Island and in the eastern of Maluku. In the western of Philippines occurred a synoptic scale weather phenomenon called Typhoon Hagupit. For the Biak region was an area of convergence that caused air masses to converge, or come together to Biak. Some of these conditions supported to the occurrence of the heavy rain in Biak.

3.2. The Atmospheric Physical Analysis

3.2.1. MJO phase analysis

Figure 3 (a) showed the OLR anomalies on the early December 2014. Indonesia was blue shaded, categorized as low OLR level. It indicated that there were many cloud cluster mainly convective clouds covered Indonesian region including Biak. The figure 3 (b) showed RMM index was in the fifth phase, indicated by convective activities in the maritime continent (Indonesia). By early December 2014, the MJO (Madden-Julian Oscillation) phase shifted eastward so that enhanced convection centered over the maritime continent (Indonesia). While, anomalous convection was weak across the central Pacific. So that, the MJO supported convection activities that produced convective clouds in Biak.

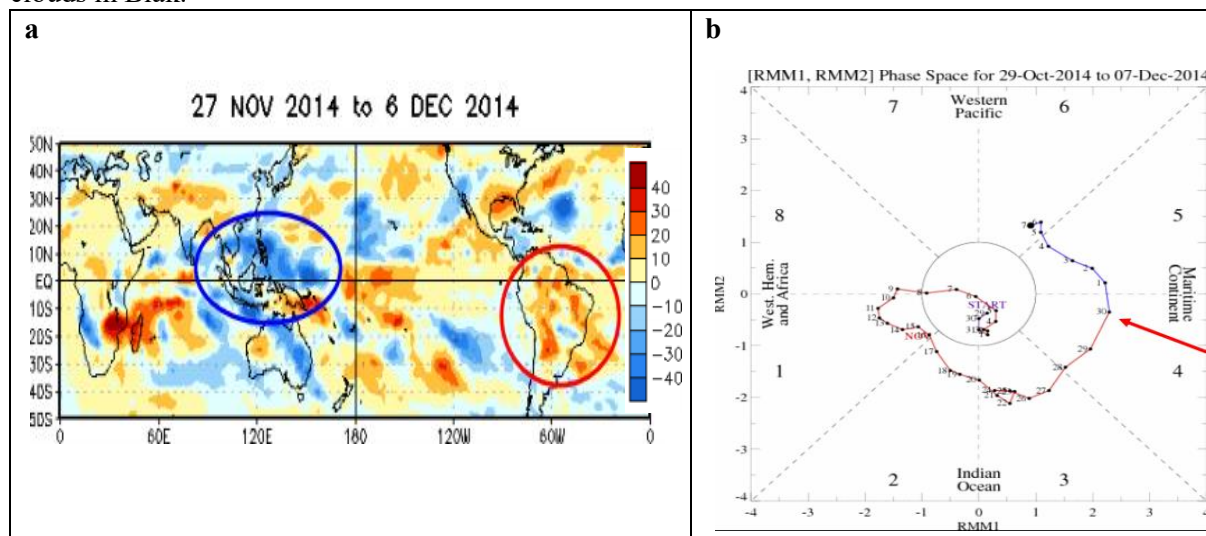


Figure 3. (a) NOAA OLR anomalies composite; (b) RMM index for MJO phase

3.2.2. Sea surface temperature analysis

Based on the satellite measurement conducted by NOAA (National Oceanic and Atmospheric Administration) of the daily average of sea surface temperature and sea surface temperature anomaly, the sea surface temperature on 3-5 December 2014 in the sea around Biak was in the range of value between 29.5°C – 31.5°C. It considered a warm category. Increasing sea surface temperature indicated increasing energy in the sea that gave possibility increasing evaporation in the atmosphere [1]. It also indicated that the water supply was still available in the formation of convective clouds in the sea around Biak. A fairly active convective clouds growth had heavy rain and thunderstorm potential. Sea surface temperature anomaly was in the range +1.0°C - +1.50°C to its normal. The warmer sea surface temperature anomalies generated convective cloud forming because it had enough latent energy [9].

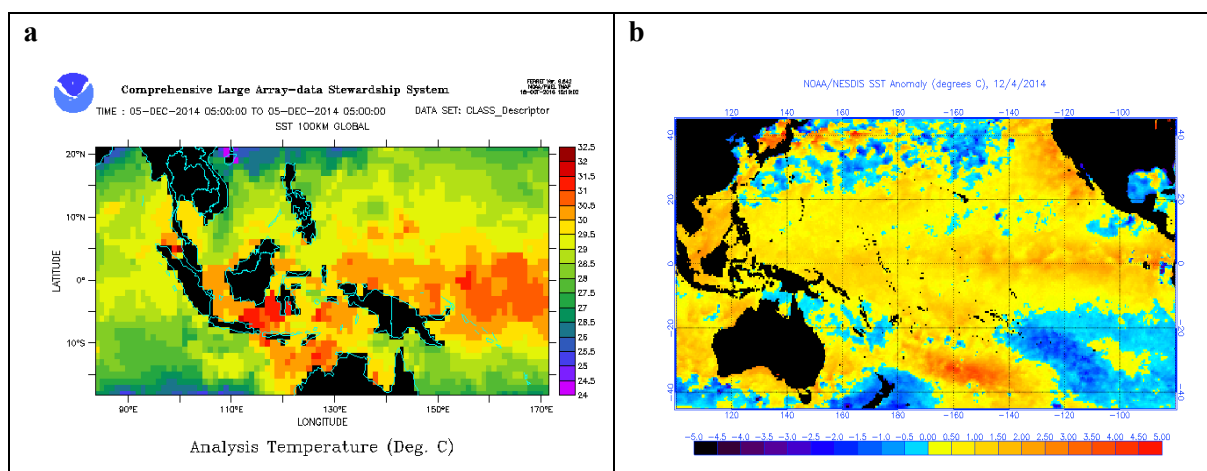


Figure 4. (a) Sea surface temperature on 5 December 2014; (b) sea surface temperature anomaly for three days (4–6 December 2014)

3.2.3. ENSO phase analysis

The SST anomalies based on Oceanic Nino Index, on December 2014 reached $+0.6^{\circ}$ and considered as weak El Nino. In this condition, the Walker circulation shifted to the eastward in Pacific. There was convergence movement in the central and the eastern Pacific due to increasing rising air in the region. While, in Indonesia, the air mass diverged due to sinking air. The influence of El Nino on eastern maritime continent was decreasing rainfall [8]. So that, in weak El Nino condition, Biak monthly rainfall decreased but not significant.

3.3. Upper Air Sounding Analysis

Local scale is used to determine the convection factor of an area, which is used to determine the vertical cloud growth area [17]. Meteorologists are concerned with static stability parameters to understand convective weather patterns [16]. If the atmosphere is unstable with abundant low-level moisture and a mechanism exists to lift the air (thereby releasing the potential instability), convective weather and rainfall (showers) can develop.

Based on the analysis of stability indices in Table 1 on the day of the super heavy rainfall weather phenomenon occurred and the previous two days showed an increased stability indices values such as LI (Lifted Index) and CAPE (Convective Available Potential Energy). Lifted Index analysis showed that the stability value during heavy rain occurred was quite high than two days before in the amount of -3.76, while two days before only reached -2.49 and -3.09. The negative LI value that reached -3.76 indicated a strong thunderstorm potential. Although the KI index showed a lower value than two days before, KI analysis was used to identify potential convective still showed a high stability value on the day of the super heavy rain occurred in the amount of 33.70. KI value was in a moderate condition which indicated a thunderstorm potential 60-80%. The analysis of SI index showed that the SI Index value was in the amount of -0.05 indicated a weak potential of the thunderstorm. Based on potential energy analysis in Biak, CAPE index value (Convective Available Potential Energy) of 1720 J/kg was in moderate convection category showed the enough energy potential in convective potential. While SWEAT index that commonly used for tornado and thunderstorm system prediction showed a lower value on the day heavy rainfall occurred than the previous two days.

Table 1. Atmospheric stability indices value on 2-4 December 2014

Date/ Index	LI	KI	SI	SWEAT	CAPE [J/kg]
2 Dec	-2.49	36.10	-1.07	248.8	523.7
3 Dec	-3.09	35.20	0.00	252.4	1425.0
4 Dec	-3.76	33.70	-0.05	216.0	1720.0

3.4. Satellite Imagery

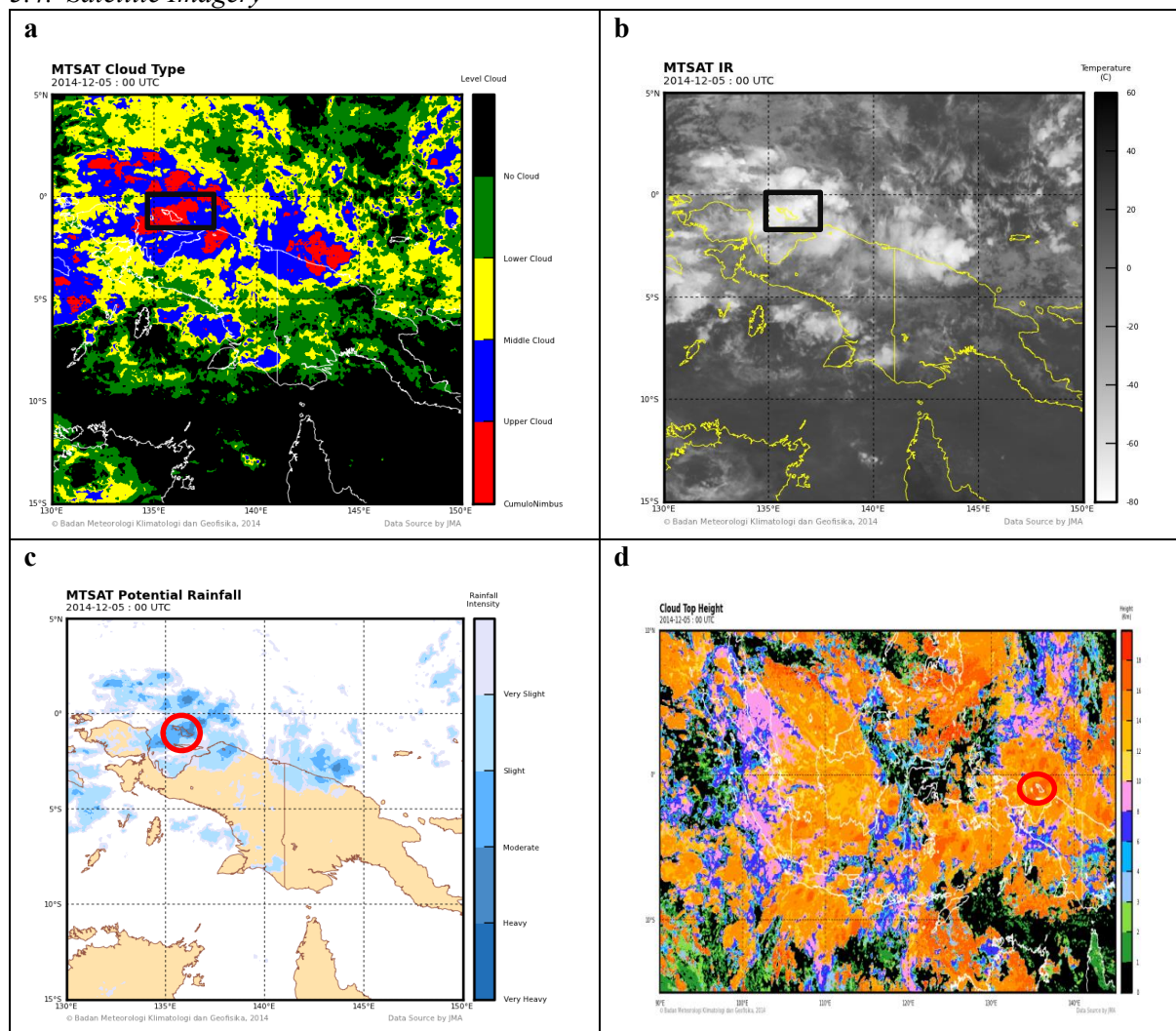


Figure 5. (a) MTSAT Cloud type imagery at 00 UTC, 5 December 2014; (b) MTSAT channel IR at 00 UTC, December 2014; (c) MTSAT Cloud Type Height at 00 UTC, 5 December 2014; (d) MTSAT Potential Rainfall at 00 UTC, 5 December 2014

According to the analysis of satellite imagery MTSAT Cloud Type BMKG on 4 December 2014 at 18:00 UTC until 5 December 2014 at 04:00 UTC showed convective cloud cover, cumulonimbus cloud (red area), above Biak region. This convective cloud cover condition was also supported by the analysis of satellite imagery MTSAT channel IR on 4 December 2014 at 18 UTC until 5 December 2014 at 04:00 UTC. From the cloud temperature that showed in Figure 2 showed that the cloud top temperature was in the range of -40°C to -80°C . The negative cloud temperature associated with cumulonimbus cloud and cirrus cloud. But in this case, the type of cloud above Biak region was cumulonimbus cloud. The negative cloud top temperature values can be used to estimate the height of

cumulonimbus cloud in the troposphere. Analysis of satellite imagery MTSAT Cloud Top Height on 4 December 2014 at 18:00 UTC until 5 December 2014 at 04:00 UTC indicated that the cloud top height was in the range of 12-18 km. The rainfall potential that showed from the analysis of satellite imagery MTSAT Potential Rainfall in Biak region indicated the potential was in the category of slight to very heavy with the dominance potential was heavy rainfall.

4. Conclusion

Research on the atmospheric conditions analysis of the super heavy rain phenomenon in Biak on 4-5 December 2014 gave the conclusion. The atmospheric conditions analyzed in dynamical and physical aspects. From the atmospheric dynamical analysis, the negative divergence value in the lower troposphere and negative relative vorticity value in middle troposphere indicated there was air mass convergence movement in Biak. The positive divergence value in higher troposphere indicated a divergence area which identical to rising air movement where the boundary layer was in unstable condition and supported for convection activities. Streamline analysis at 3000 feet showed low-pressure areas in the north of Papua and in the eastern of Maluku. In the western of Philippines occurred Typhoon Hagupit. Besides that, Biak was in an ITCZ area. All these conditions could be a trigger for convective cloud cluster forming.

Atmospheric physical analysis showed a low OLR anomalies value that indicated a convective cloud cluster covered maritime continent region including Biak. MJO was in phase 5, indicated by an enhancement in convection activities that centered over the maritime continent. Sea surface temperature condition and its anomalies analysis showed a warm sea surface temperature and a warmer anomaly. These conditions supported for convective cloud forming in Biak region. While ENSO phase analysis indicated a weak El Nino where Biak Monthly rainfall decreased but not significant. Upper air sounding analysis showed an increased stability indices values such as LI and CAPE. Lifted Index value of -3.76 during heavy rain occurred was quite high than two days before, while two days before only reached -2.49 and -3.09. The negative LI value indicated a strong thunderstorm potential. Moreover, CAPE index value of 1720 J/kg had a huge potential energy which can be a trigger for convective cloud development. On the other hand, other stability indices were not describing upper air condition appropriately for the super heavy rain phenomenon.

Based on analysis of MTSAT satellite imagery showed a convective cloud cover, cumulonimbus type above Biak region where the cloud top temperature was is in the range of -40°C to -80°C and the cloud top height was in the range of 12-18 km. These indicated heavy rainfall potential in Biak region. Most of the dynamics and physical analysis of the atmospheric conditions in Biak on the dates were proved and supported to super heavy rain phenomenon occurred.

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